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## SUBJECT REVIEW

# Treatment of developmental dyslexia: A review

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### Abstract

Remarkably few research articles on the treatment of developmental dyslexia were published during the last 25 years. Some treatment research arose from the temporal processing theory, some from the phonological deficit hypothesis and some more from the balance model of learning to read and dyslexia. Within the framework of that model, this article reviews the aetiology of dyslexia sub-types, the neuropsychological rationale for treatment, the treatment techniques and the outcomes of treatment research. The possible mechanisms underlying the effects of treatment are discussed.

**Keywords:** *Developmental dyslexia, dyslexia sub-types, techniques for treating dyslexia, results of treatment*

Muy pocos artículos de investigación acerca del tratamiento de la dislexia en el desarrollo fueron publicados durante los últimos 25 años. Algunas investigaciones de tratamiento surgieron a partir de la teoría del procesamiento temporal, algunas a partir de las hipótesis de la deficiencia fonológica y otras más a partir del modelo de equilibrio del aprendizaje para la lectura y la dislexia. Dentro del marco de referencia de ese modelo, este artículo revisa la etiología de los subtipos de la dislexia, el razonamiento neuropsicológico para el tratamiento, las técnicas de tratamiento y los resultados de las investigaciones de los tratamientos. Se discute el posible mecanismo detrás de los efectos del tratamiento.

### Introduction

Treatment of developmental dyslexia? In entering the word 'dyslexia', the Web of Science delivered 3871 articles from 1975 onward. If 'treatment of dyslexia' was entered, only 32 articles showed up in that period, less than 1% of the total production on dyslexia. Using 'rehabilitation of dyslexia' or 'intervention in dyslexia' didn't change that figure. Thus, a history of dyslexia treatment apparently doesn't cover much published work. Of the 32 scientific articles on treatment published over the last 25 years, a number concerned an overview, leaving fewer than 32 papers that published the results of original experimental investigations into the effects of a particular treatment.

Practice is different though. Hundreds of institutes, all over the world, offer programmes meant to facilitate the reading of dyslexic children. They have to, is an often heard excuse, because millions of dyslexic children cannot wait until the time

when science can offer research-based treatment programmes. Whatever one thinks of such practice, one of the undesirable outcomes can be that children, parents, health professionals and public authorities get disappointed about the way institutes handle dyslexia.

What could be the reason that remarkably little effort has been put into treatment research thus far? One reason is obvious and legal: one would wish to know enough about the aetiology of developmental dyslexia before one starts investigating suitable treatment procedures. That the two of these show mutual influencing though is also true. Due to the availability of modern imaging techniques, including ERP (event-related potential measuring) and MEG (magneto-encephalography), the aetiology of dyslexia is slowly losing its secrets. As a consequence, one is inclined to expect the development of new treatment programmes in the near future. However, there are other reasons why few science-based

treatment programmes showed up in the recent past. Treatment research is a complex affair. It is not really easy to control for all possible intervening factors that, beside the factor to be investigated, may be responsible for the treatment effects found. For example, if it is reported that dyslexic children profit from a particular method then such a finding may be a stroke of luck for the children engaged, from a scientific point of view the reported finding is of little value. Maybe it was not the method itself that caused the positive outcome, but rather the motivating and stimulating behaviour of the person who applied the method. Thus, control of these and many other effect-inducing factors is a necessity. This being the case, treatment research not only is complex, it also is time-consuming and costly.

Once again, having an eye on the 32 publications mentioned above, it appears that some treatment research has the psycholinguistic problems of dyslexics as a starting platform, that for some other research this is the so-called temporal processing theory and that a few papers address the reading effects of other approaches. More papers though are based on the so-called balance model of reading and dyslexia, originally developed and investigated by the present author. That being the case, this historical overview mainly contains the theory concerning and the findings emerging from the balance model.

## Development of a model

### *Original thoughts*

Those who have to master English script encounter many pitfalls as English shows a relatively low correlation between graphemes and phonemes. The Germanic languages seem somewhat less complex in this respect. Indeed, the task to transform quite a few different letters into the corresponding sounds must be tough for children. Correctly perceiving a letter and discriminating this letter from the other ones is a burden for the perceptual system. The more so as the letter shapes do not show the perceptual constancy the child is already familiar with. Perceptual constancy: An object or shape keeps its meaning, irrespective of its position in space. Thus, an apple is an apple, whether viewed from above or from below, from the right or from the left. However, turn a 'b' around and it becomes a 'd', a 'p' or a 'q'. Perceiving letters is even more perplexing when one considers the fact that changing their shapes may have no consequences for their meaning: A 'd' and a 'D' are pronounced exactly the same way. An array of letters may compose a word, but the same letters may produce different words: 'mean', 'mane', 'name' and 'amen'. Thus, the meaning of a word, among other things, depends on the left-to-right arrangement of

the constituent letters. Similarly, the meaning of a sentence may depend on the lateral arrangement of the words: 'The cow is on the car' and 'the car is on the cow' tell us very different events.

Thus, the processing of text is perceptually demanding at the onset of learning to read. Because of that the right cerebral hemisphere will have a lion's share in that process. Gradually, the nature of reading changes though. Perceptual analysis of the letters becomes an automatism, the lexicon grows and the child becomes familiar with text. Reading no longer proceeds bottom-up but rather top-down. All this is needed to have the child reading with fluency. Due to its lingual nature, advanced reading is primary matter for the left cerebral hemisphere.

Some evidence is available in support of the right-to-left shift in the hemispheric subservience of reading, at some point during the learning to read process. Licht et al. [1] did a 4-year longitudinal study with kindergarten children. They registered electro-physiological activity elicited by centrally flashed words. Reading at kindergarten and the first grade of primary school appeared to be mainly associated with activity evoked in the right hemisphere and reading at later grades with activity evoked in the left hemisphere. The results of their investigation are represented in Figure 1.

The findings reported by Licht et al. [1] were recently underscored by those of Turkeltaub et al. [2] who showed that the cerebral correlates of reading gradually move from the right to the left side of the brain.

Every normal development can have a counterpart: There may be children who are not able to make the hemispheric shift in the primary subservience of reading. This inability may be caused by a disturbance in the anatomy of the left hemisphere [3]. As a result, these children may get stuck in the generation of right hemispheric reading strategies. They keep the style of reading that is characteristic of initial stages in the learning to read process: relatively slow and fragmented. These reading disabled children were denoted P-type dyslexics or 'spellers' [4,5]. When the aberrance is in the right rather than the left hemisphere, then the left hemisphere may take over reading subservience too early [3]. As a consequence of that, these children will be inclined to read in a speeded fashion, but, as they have 'no eye' for the perceptual features of text, they will make many mistakes. These reading disabled children were denoted to suffer from L-type dyslexia; they are also called 'guessers' [4,5].

### *Remodelling the brain*

One of the most challenging questions in education is how to treat dyslexia. Within the framework of the

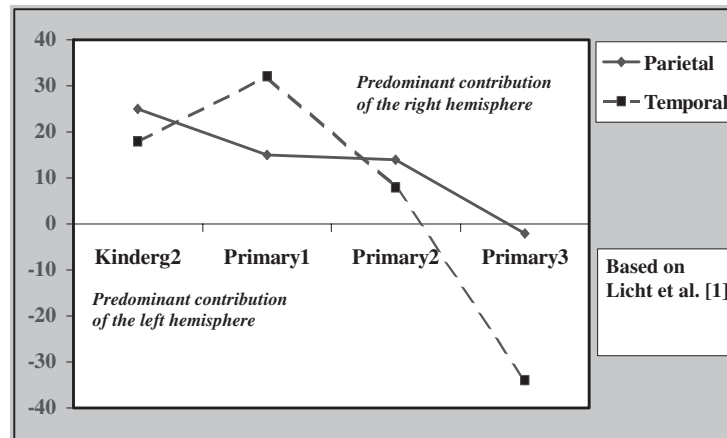


Figure 1. Development of reading-hemisphere dependency as reflected by word-elicited potentials.

presumed balanced involvement of the two cerebral hemispheres in learning to read, an obvious answer to this question is to stimulate the under-activated hemisphere. P-types would need stimulation of the left hemisphere and L-types of the right hemisphere. However, what kind of stimulation should that be? It is well known that appropriate exercises are able to boost the capacities of muscles. Would selective stimulation of the brain have comparable effects? Indeed, it would. One of the fascinating discoveries of the last decades is the demonstration that the brain is prepared to change according to stimulation from the psycho-social and educational environment [6,7]. Just a few examples of what education is able to do. Castro-Caldas et al. [8] had literate and illiterate Portuguese adult women to repeat orally presented meaningful and pseudo-words. During these tasks, cerebral activation was investigated through PET-scans. The patterns of activation in the literate vs illiterate subjects were found to be different, especially for the pseudo-words. The investigators concluded '... that learning to read and write during childhood influences the functional organization of the adult human brain' ([8], p. 1060). It would be interesting to know what would happen with their pattern of activation, in case the illiterate adult subjects would, as yet, learn to read and write. In this respect, work done by Neville, as reported by Barinaga [9], is imaginative. Adults, who had arrived in the USA as immigrants when they were 1–3, 5–7 or 10–13 years of age, were presented surprising sentences such as 'the fish is swimming in the air'. During processing the sentences brain activation was measured through modern imaging techniques. One would expect that areas within the left cerebral hemisphere would light up, as the information presented was lingual in nature. That happened indeed in those who were youngest at the time of immigration. Immigrants though who had arrived at the English speaking environment at later ages showed activation within

both brain hemispheres while processing the sentences. These and many other examples illustrate the enormous flexibility of the central nervous system. One should consider the readiness of the brain to adapt to the environment in a concrete sense. In many experiments it has been shown that quite a number of anatomical, physiological and biochemical brain parameters change in response to new environments an organism is exposed to [10]. So-called enriched environments, including tasks that require higher levels of learning effort, may induce extensive dendritic branching and synapse formation, larger amounts of certain neurotransmitters, changing RNA/DNA ratios and more.

Thus, trying to enhance the involvement of one or the other hemisphere in reading seems a legitimate venture. Indeed, the lateral distribution of hemispheric activity did change in P- and L-type dyslexic children in response to hemisphere-specific stimulation. It did so in a differential fashion, depending on whether the left side of the brain was stimulated in P-dyslexics or the right side in L-dyslexics [11,12]. Kappers and Hamburger [13] did a single case study with a severely dyslexic boy. Before and after the treatment visual maps were produced of, among others, the lateral distribution of the P300 peak, as evoked by visual patterns shown to him. The boy had received specific stimulation of the right hemisphere for quite some time. When it appeared that the accuracy of his reading had improved considerably it was decided that from then on his left hemisphere should be stimulated, in order to enhance the fluency of his reading. Before treatment, the distribution of P300 voltage was largely bilateral whereas after treatment one clearly saw a lateral shift to the left hemisphere. Why not to the right, as the right hemisphere was stimulated initially? One possible answer is that an initial rightward distribution was over-ruled by a final leftward move, induced by the stimulation of the left hemisphere at last. However

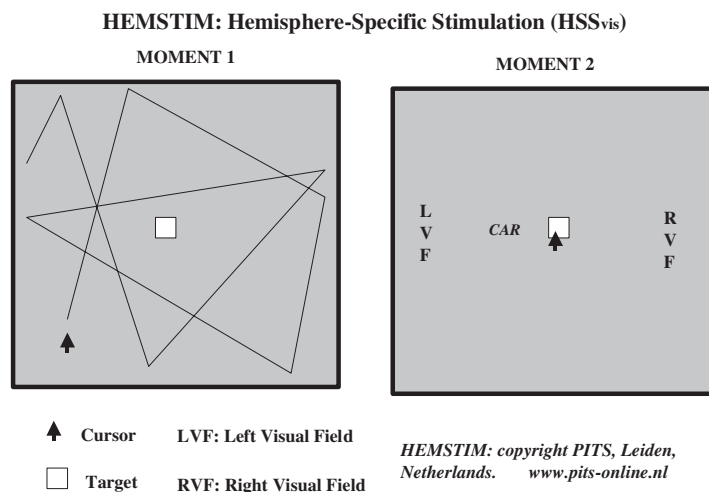


Figure 2. Layout of the HEMSTIM computer program for hemisphere-specific stimulation through the visual channel (HSS<sub>vis</sub>).

that may be, the point here is that hemisphere-specific stimulation with flashed words does have a pronounced effect on the lateral distribution of brain activity.

### Hemisphere stimulation: Techniques

Taking advantage of the crossed relationship between the periphery of the body and the central nervous system, one can flash words in the left visual field to stimulate the right hemisphere or in the right visual field to stimulate the left hemisphere. This type of treatment is called hemisphere-specific stimulation through the lateral visual fields (HSS<sub>vis</sub>). Flashing times shall be shorter than 300 ms. Of crucial importance is that the child fixates the centre of a screen at the very moment of flashing a word left (for L-types) or right (for P-types) of that fixation point. The HEMSTIM-programme can be used to accomplish HSS<sub>vis</sub> (Figure 2).

Sometimes HSS<sub>vis</sub> is used in combination with HSS through the auditory channel (HSS<sub>aud</sub>). In that case a word flashed is read aloud by the child and its own voice is heard in the left (L-type) or right (P-type) ear. HSS through the ears is somewhat problematic though as each ear projects onto both hemispheres, albeit to the contra-lateral hemisphere predominantly. It is simpler to present (plastic) letters to the fingers of the right or left hand, in order to stimulate the left or right hemisphere, respectively. This type of treatment is denoted hemisphere-specific stimulation through the tactile receptors of the hands (HSS<sub>tac</sub>). Simpler indeed, but also somewhat unnatural, as reading normally is matter for the eyes rather than the hands. Easily practicable in the classroom is the so-called method of hemisphere-alluding stimulation (HAS). In order to enhance involvement of the right hemisphere in reading (L-types), texts are percep-

tually loaded by mixing different typefaces within a word. Such a text will appear to be hard to read, as it requires quite some perceptual analysis of the letters. Conversely, one may create texts that allude to predominant left hemispheric involvement in the reading of P-types. Such texts contain many words to be found by rhyming on other words, a process that implies phonemic effort.

These techniques, either separately or in combination, have been experimentally and clinically investigated within different language domains.

### Treatment effects

Would specific or alluding stimulation of the left hemisphere in P-type dyslexic children and the right hemisphere in L-type dyslexic children make any difference with regard to the quality of their reading? (The publication by Smit-Glaudé [14] was of great help in reviewing the treatment studies.)

The start was modest: Altogether, 19 8–13 year old P- and L-dyslexic children participated in a pilot study [11]. Three groups were created, an experimental group which received hemisphere-specific stimulation (HSS<sub>vis</sub>+aud), a first control group which received standard remedial teaching and a second control group which was withheld from any extra training. There were 16 treatment sessions, divided over 8 consecutive weeks, with each session lasting for 45 minutes. Reading was assessed before and after treatment, as were word-elicited potentials at right and left, parietal and temporal areas. The results showed the experimental P- and L-children to improve significantly more than both control groups. According to prediction, the lateral distribution of electro-physiological activity also proved to have changed in the experimental P- and L-type children. Relatively more activity was found over the left



hemisphere in P-children (who had received stimulation of that hemisphere) and relatively more activity over the right hemisphere in L-children (who had received stimulation of that hemisphere). No such post- vs pre-test changes were observed in the control groups.

These outcomes were felt encouraging and it was, thus, decided to move on. Bakker and Vinke [12] had 35 L-type dyslexic children and 35 P-types; the average age was 10 years. The children were divided into five treatment groups, within type of dyslexia. Of these groups, two were experimental and three were control groups. The experimental groups received either HSSvis or HAS in P-types to stimulate the left hemisphere and in L-types to stimulate the right hemisphere. The first control group received bilateral stimulation in that words were flashed in the central visual field. The second control group was presented counterbalanced HAS: In the one session it concerned HAS for P-types, in the other for L-types. The third control group didn't receive any treatment. Reading tests were administered before and after treatments, as were word-related potentials. There were 22 weekly sessions, each session lasting for 45 minutes. In general, the results were the same as in the study by Bakker et al. [11]. HSSvis showed better treatment effects in L-type dyslexic children, HAS did better in P-types. It was found that post- vs pre-test changes in the lateral distribution of the parietal P250 component correlated with improvements in reading.

These outcomes were even more encouraging, but what would happen if this neuropsychological treatment would be used in a different language domain? In a multiple single-case study in Finland, Neuvonen et al. [15] had P- and L-dyslexic children treated through HSSvis in 16 sessions, equally divided over 8 weeks. Control children received standard remedial teaching. It was reported that the HSS-treated P- and L-children improved more than the controls on all aspects of reading.

Russo [16] did a study in the US, using under-achievers in reading who demonstrated an L-type reading strategy. They received HSSvis for 7 weeks, followed by HSStac for 7 weeks. There were three sessions per week and each session lasted for some 15 minutes. Using the same treatment schedule, other P- and L-dyslexic children received word games as control training. A second control group didn't receive any treatment. Russo reported that the HSS-treated L-type under-achievers improved much more in reading accuracy and comprehension than did the alternatively trained and control children.

So far so good, but then the sky became somewhat cloudy. Grace and Spreen [17] did a study in Canada and they did so in two phases: a pilot and a main study. The design of both studies is similar to the

design used by Bakker and Vinke [12]. The same is true when it comes to the results of the pilot study: Improvement of reading after HSSvis and also the predicted changes in the lateral distribution of hemispheric activity. The outcomes of the main study were quite different though. Certainly, a few results were in accordance with the predictions, but one puzzling outcome was that L-dyslexics who had received right hemisphere stimulation, vs L-controls became less accurate in reading. The finding that their left rather than their right hemisphere became more active is interesting though. If the left hemisphere shows more activity after treatment, one may expect reading accuracy to worsen indeed. Thus, the crucial question is not why accuracy worsened but why the left hemisphere became more active after stimulation of the right hemisphere.

In the mean time, several Dutch studies were published. Bakker et al. [18] did a countrywide investigation with the assistance of local remedial teachers. They were asked to classify the dyslexic children referred to them as P- or L-types; 98 subjects were registered. These children either received HSStac or a control treatment, the latter according to the practice of the remedial teacher. There were 20 treatment sessions. During pre- and post-treatment periods, but also halfway treatment sessions, a number of commonly used word and text reading tests were administered, as were some other cognitive tests. Compared to the control group, the HSS-treated P-group showed improvement of word-reading fluency while the L-group demonstrated better text-reading accuracy. These findings are in accordance with predictions. The improvement in word reading by the P-children was more robust than the improvement in text reading by the L-children. This finding may indicate that the slow tactile channel is more appropriate for the relatively slow reading P-types and that the fast visual channel is more appropriate for the relatively fast reading L-types.

Van Strien et al. [19] applied HSSvis and the words they flashed were emotionally either neutral or anxiety-laden. There is some evidence suggesting that negative emotions are predominantly mediated by the right cerebral hemisphere [20]. The authors reasoned that the effect of right hemisphere stimulation in L-types might be strengthened by the negative emotions induced by the anxiety-laden words. That is what they actually found: Less reading errors in the L-children having received anxiety words in comparison with the L-children who had been flashed neutral words. The threatening words were found to have a negative effect in P-children whose left hemisphere had been stimulated: They read even slower than they did already and slower also than the P-children who had received the neutral words.

Spyer [21] investigated the effects of HSS and the nootropic drug piracetam (2oxo-1 pyrrolidine acetamide) on the reading performance of dyslexic children. The positive effect of this drug on the reading quality of dyslexic subjects has been reported in a number of publications [21]. Only P-type and so-called non-typed (neither P nor L), 8–13 year old dyslexic children were involved in Spyer's main study. The P-children were divided in four treatment groups: Placebo, Piracetam, Piracetam + HSSvis of the left hemisphere and Placebo + HSSvis of the left hemisphere. The non-typed children similarly were divided in four treatment groups: Placebo, Piracetam, Piracetam + HSSvis of either the left or the right hemisphere and Placebo + HSSvis of either the left or the right hemisphere. In the case of either left or right hemisphere stimulation, one child received left hemisphere stimulation and the other right hemisphere stimulation over the course of the study. All subjects received 12 weeks of double-blind treatment with piracetam (in solution,  $0.33 \text{ g ml}^{-1}$ , 3.3 g daily) or placebo. HSSvis was provided in 30 minute sessions, twice weekly, over a period of 12 weeks. Pre-, intermediate (after 6 weeks of treatment), post- and follow-up (8 weeks after termination of treatment) tests included word and sentence reading as well as a few other cognitive tests. The results regarding HSSvis in P-children were disappointing in that they were found to read words and sentences less rather than more fluently after treatment. After stimulation of the left hemisphere, one would expect better fluency. Piracetam was reported to have a facilitating effect on left hemispheric functioning. According to the balance model one would then expect fluency of reading to increase. Piracetam medication tended to such an effect on the fluency of word reading in P- and non-typed dyslexic children. The unexpected effect of HSSvis in P-dyslexia might be due to the sensory input channel used. The results obtained in the Bakker et al. [18] study do suggest that HSStac is more appropriate as a treatment of P-dyslexia than is HSSvis. Spyer [21], in an effort to clarify this issue by comparing the outcomes of HSSvis versus HSStac treatment, on the basis of the outcomes was not able to definitely settle the problem.

Struiksmā and Bakker [22] drew up an inventory of the outcomes of intervention over a long period (on average 79 sessions) during which 40 severely dyslexic children were treated according to the principles of the balance model. Treatment-induced improvement was 8 and 12 months for word and text reading, respectively. Interestingly, those who were poorest before treatment showed the least improvement. Interesting also was the finding that the relatively poorest and best readers at treatment onset demonstrated a large discrepancy in improvement on word

reading, the initially poorest readers gaining less than the initially best readers. A similar discrepancy was hardly present for text reading.

After these early investigations, research into the efficacy of HSS and HAS continued and around the change of the millennium a number of new publications was issued. Most of this research concerns the question whether the neuropsychological techniques are useful in the clinic and in the (special) school. Importantly though, some other recent research addresses the possible mechanisms involved in the effects of HSS and HAS. It is clear that stimulation of a single hemisphere affects the lateral distribution of word-elicited activity but this fact doesn't tell which reading-subserving mechanisms are involved.

Kappers [23] investigated the efficacy of HSS and HAS in the setting of an outpatient clinic. Treated were 80 severely dyslexic children who were at least 2 years backward in reading. The number of treatment sessions was variable; for a few children treatment went on for 2 years. After each period of eight sessions the reading level of the subjects was examined. In a pre-clinical phase, that is before HSS and HAS was supplied (clinical phase), the children received training through the flashing of word cards. Directly after the clinical phase the children's reading was examined once again and so was done in follow-ups, 6, 18 and 24 months after completion of clinical treatments. The methodological design and statistical analyses employed by Kappers [23] were most advanced. As a result, he was in the position to deliver the variances in the data accounted for by each of the components in the treatment. Thus, he could demonstrate that the pre-clinical training with word cards had a significant positive effect on reading performance, but that the HSS- and HAS-induced improvements in word and text reading were much larger. No less than 86% of the children showed improvement in word reading and 91% in text reading; 46% of the children had obtained a normal word reading level and 55% a normal text reading level. Profit was not found to decrease significantly at the follow-ups. The outcomes were not affected by gender or by IQ. Left hemisphere stimulation in P-children and right hemisphere stimulation in L-children didn't produce different outcomes. Like Struiksmā and Bakker [22], Kappers [23] found that those subjects who were relatively best at intake were also the ones who profited most from treatment.

Van Daal and Reitsma [24] used Kappers' group of severely dyslexic children, supplemented with recent intakes. Different from Kappers, the authors not only accepted cases suffering from pure dyslexia but also cases with co-morbidity (cognitive, behavioural or psychiatric pathology). Their group totalled 163 subjects. The results were quite comparable with

those obtained by Kappers. Cases with dyslexia only profitted most and, once again, those who performed relatively best at intake showed the best results after treatment. Neither level of intelligence nor the presence of speech or language problems affected the outcomes.

In another child-psychiatric institute, Van den Bungelaar and Van der Schaft [25] had 30 severely dyslexic children: 15 children were treated with appropriate hemisphere stimulation, while 15 matched controls were on the waiting list. Treatment lasted for 6 months and there were two sessions a week. The outcomes in essence were the same as those obtained by Kappers and by Van Daal and Reitsma: Large profits from treatment and no observable effects of IQ and age.

Robertson [26,27] in the UK, Bodien [28] in Bahrain, Goldstein and Obrzut [29] in the USA and Kim [30] in South Korea investigated the fruitfulness of hemisphere stimulation in a school setting. Both Robertson and Goldstein distinguished P-, L- and M-dyslexia, M denoting 'mixed', which concerns children with both P and L characteristics. Robertson, in a controlled fashion describes the results of HSS and HAS in multiple single cases. In using the NARA-test she reported improvement of reading accuracy, especially in L-types, improvement of reading fluency in P-types and improvement of reading comprehension, especially in L-types.

Essentially, similar results had been reported by Bodien [28], who used HAS for right hemisphere stimulation in a single L-dyslexic case. While using the Neale test, Bodien showed accuracy of reading and reading comprehension especially to improve steadily over sessions, but not so did speed of reading. She also found increments of word reading on the British Ability Scales.

Goldstein and Obrzut [29] had 11–15 year old dyslexic children from a secondary school, classified as either P, L or M (15 subjects in each group). The P- and L-group received 16 sessions of intervention, one 40 minute-session per week. Each session consisted of 5 minutes HSSvis, 15 minutes HAS and 20 minutes HSStac. M-children acted as controls, they received extra weekly training in word decoding and meaning-attribution to text. It was only possible to compare the effects of type of dyslexia by type of treatment interactions. In doing so it appeared that L-children did best in that their reading accuracy and comprehension, after intervention outscored the results of the controls in these respects.

It is worth noticing that Goldstein and Obrzut [29] enrolled secondary school children in their study. Kappers and Dekker [31] and Kappers et al. [32] did so before. Kappers and Dekker had 14 dyslexic adolescents from the second grade of secondary schools; they were at least 2 years behind, both

in Dutch and English word and text reading. Treatment was in 30 sessions, two sessions per week. Either HSSvis or HSStac was used, both in combination with HSSaud. Eight subjects received Dutch words flashed in the right (P) or left (L) visual field, for six subjects these were English words. All pupils improved in Dutch and English word and text reading, irrespective of whether Dutch or English words had been used for hemisphere stimulation. Conform expectation accuracy of reading improved in L-type dyslexics. Contrary to expectation was that their reading fluency also improved. Kappers et al. [32] repeated the study using a larger sample: 17 youngsters were flashed Dutch words in one of the visual fields and 14 were flashed English words. In this investigation, HAS was an additional treatment modality. The results matched the ones obtained by Kappers and Dekker [31]. Virtually all aspects of reading improved, fluency in reading English texts being an exception.

Dutch, English, Finish: Korean clearly is a very different language. Kim [30], in using a multiple probe design, explored the effects of hemisphere stimulation (HSSvis, HSStac and HSS) in three P- and three L-dyslexic children from primary school grade 3–6. Treatment was in 30–50 daily sessions, each session lasting for 20 minutes. Kim reported that:

- (1) Reading accuracy in the L-children had improved,
- (2) Reading fluency in P-children had improved, and
- (3) Degree of improvements was maintained 7 weeks after termination of treatment.

Seemingly different from most studies discussed were the findings of Dryer et al. [33] in Australia. The investigators had 40 10-year old P- and L-type dyslexic children who either received left or right hemisphere stimulation through a combination of HSSvis, HSStac and HAS provided for within sessions. Thus, two groups of children were challenged: P-types receiving right hemisphere stimulation and L-types receiving left hemisphere stimulation. There were 24 treatment sessions, four sessions per week. Overall improvement in accuracy on the GORT-R test was 77.6%. As no control treatment was used, it is not really possible to value this robust effect. The investigators did not find a significant effect of dyslexia-type or hemisphere of stimulation, which suggests that it doesn't make much difference which hemisphere is stimulated and that single hemisphere stimulation as such will do. In that case, one would wonder which hemispheric function is affected by unilateral stimulation.



Before addressing this crucial question, the design and results of a recent long-lasting longitudinal study will be discussed. The study is by Smit-Glaudé [14] and Smit-Glaudé et al. [34]. Virtually all grade-one kindergarten children of a school district participated. The teachers were requested to indicate whether a child would most likely, likely, doubtfully, unlikely or most unlikely develop a language/reading problem in the future. Those who were considered most likely or likely at risk were administered the Dutch version of the Florida Kindergarten Screening Battery. Performance-scores were factor-analysed and subjects performing relatively highly on the perceptual factor and relatively lowly on the verbal/lingual factor were denoted Latent P-types (LAP). Subjects demonstrating the reverse pattern were denoted Latent L-types (LAL). The validity of the LAP/LAL classification was investigated, using an independent test battery and evoked cortical responses to meaningful pictures. The classification was found satisfactory valid and it also appeared that the lateral distribution of the evoked responses, in a number of respects, differed between LAP- and LAL-children. Both the LAP- and LAL-group were each divided in four intervention groups. Two LAP-groups received stimulation of the left hemisphere (LAP-L), one through HSSvis and one through HAS. One LAP group received bilateral stimulation by flashing words to read in the central visual field (LAP-B). The fourth group did not receive any intervention (LAP-N). Two LAL groups similarly received stimulation of the right hemisphere (LAL-R), through HSSvis or HAS. Another LAL group received bilateral stimulation (LAL-B), whereas a fourth group was held back from any intervention (LAL-N). There were 10 sessions at the end of kindergarten grade 2 and five sessions at the beginning of primary school grade 1; the sessions were once a week and they lasted for 45 minutes approximately. Standardized word and text reading tests were administered at the end of primary school grade 1 and also in grades 5/6. Backwardness or forwardness in reading, in months, could be established. Two main questions were addressed: Are these children in general backward in reading and does it make any difference which type of intervention was employed? The answer to both questions was positive. LAP- and LAL-children were found significantly backward in word and text reading, both at the start and at the end of primary school; kindergarten teachers are good predictors, indeed. However, type of intervention made a difference: Non-intervened LAP-children as well as LAL-children who had received right hemisphere stimulation were not significantly backward in early (grade 1) word reading and neither in late (grades 5/6) text reading. Most backward

in these respects and in these phases were non-intervened LAL-children as well as LAP-children who had received left hemisphere stimulation. Thus, it seems that left hemisphere stimulation in an early phase is not profitable for at risk children and that right hemisphere stimulation is fruitful. However, bilateral stimulation was not bad either, especially in latent P-dyslexia.

From the outcomes of the sampled studies reviewed, one may conclude that right hemisphere stimulation in manifest and latent L-type dyslexia is effective in that this treatment boosts the quality of reading, accuracy of reading and reading comprehension especially. Some studies show that left hemisphere stimulation positively affects the fluency of reading in manifest P-type dyslexia. Latent P-type dyslexia may be best served by bilateral stimulation. Considering the latter and considering the non-differential effects of right vs left hemisphere stimulation, obtained in the Dryer et al. [33] study, one would like to know what might mediate the outcomes of unilateral and bilateral stimulation of the brain.

### Mechanisms

Unilateral and bilateral visual stimulation share the shortening of flashing-time across treatment sessions. Thus, the flashing time of words in the very first session may be 300 ms while in the last session this may be 30 ms. Originally, this shortening intended to keep the task reasonably demanding during the course of treatment. It will be clear though that this way the child has to speed-up information processing as treatment progresses. There is a number of treatment studies, inspired by Tallal's temporal processing theory, which addressed the effects on reading of gradual enhancements in the speed of information processing [35–37]. These effects were reported to be positive. That being the case, one might consider the possibility that increments in temporal processing, as effectuated by shortening the flashing times during HSSvis and bilateral stimulation in the studies reviewed, may have contributed to the improvement of reading. A connection between the balance model and the temporal processing theory would then emerge. However, the overlap seemingly is partial only as effects of hemisphere stimulation were also obtained with treatment procedures that do not require enhancement of information processing speed: HSStac and HAS.

There is another function that stands an excellent chance to underlie the treatment effects: Attention, inhibition especially. Van der Schoot et al. [4,5], in a series of studies, showed that P- and L-dyslexic children react quite differently when it comes to the

inhibition of an already started response. L-children appeared to be relatively poor inhibitors, P-children are significantly better and even tend to outscore normal readers. Group differences in this respect could clearly be traced in cerebral activation patterns. Such a finding adds to the validity of the P/L classification of course and suggests that the ability to appropriately focus attention is an important mechanism involved in the treatment effects. This hypothesis found strong support by the research findings obtained by Facoetti et al. [38] in Italy. These authors embroidered on treatment research by Lorusso et al. [39]. Lorusso et al. had P-, L- and M-type dyslexic children who either received appropriate hemisphere stimulation or a control treatment. Following treatment, the hemisphere-stimulated groups appeared to outscore the controls on a number of reading parameters, especially on accuracy. During the pre-treatment period though, not only reading and other cognitive tests had been administered, but also an experimental, visual attention task, the task being repeated after termination of treatment. What happened is that those who had received hemisphere stimulation did show improved visual attention and those who had received control treatment did not. At this junction, two remarks are in place. First, the poor inhibition of the L-types in the Van der Schoot et al. study may tempt one to think that these L-types were not only dyslexic but that they also suffered from an attention-deficit disorder. They didn't, according to the outcomes of a pre-treatment screening to that effect. Secondly, Facoetti et al. and Lorusso et al. found the effects on reading and visual attention across dyslexia types and hemispheres. In other words, it was found that hemisphere stimulation works in dyslexic children, irrespective of the type of dyslexia and the side of the brain stimulated. Thus, Facoetti et al. reasoned, the findings with regard to visual attention make Dryer et al.'s findings with regard to reading understandable: Indeed, it doesn't make much of a difference whether the left or the right hemisphere is stimulated in P- or L-dyslexics, as long as one hemisphere is stimulated.

The attention hypothesis in fact had already been brought forward by Morris [40]. Morris suggested that stimulating a single hemisphere induces a focusing of attention and that the side of the hemisphere is not crucial. Recently, Lorusso et al. [41] presented M-type dyslexic children with different procedures to stimulate the brain. The investigators provided right hemisphere stimulation for a time and then left hemisphere stimulation for a time, vs stimulation of the left and the right hemisphere in an alternating fashion, vs bilateral stimulation, vs bilateral stimulation with a fixed word-flashing time. The subjects in general improved in reading but there was no differential effect of procedures. That

being the case it seems unlikely that enhancement of temporal processing speed played a dominant role as the results with a fixed flashing time were not found to differ from those obtained with a steadily shorter flashing time. More than one subserving mechanism may play a role in these M-type dyslexic children, the authors suggest, attention included. How this would work out in L- and P-dyslexia is not known. Saying that makes clear that the issue of the subserving mechanisms certainly is not settled yet.

One approach to dyslexia is in favour the last couple of decades: The phonological deficit hypothesis. Research is available [42] showing the practice and the effects of phonological training with a variety of procedures. Phonological analysis is part of the reading process. A metaphor may clarify at which level treatment happens when it comes to phonological training. Imagine that a wheel of a farm cart breaks down, preventing the driver to continue his journey. Repairing the wheel would do. However, possibly the driver is aware of the fact that the road is very rough. Consequently, another breakdown may follow. The wheel is part of the cart, the road rather is subserving the cart. Phonological analysis similarly is part of the reading process. In case that is the whole story about reading and dyslexia, appropriate training of phonological processing might do. However, in case one or more subserving mechanisms appear to fail, it seems more appropriate to address these mechanisms in order to establish enduring improvement.

However, the mechanisms involved in reading in turn have deeper layers of subservience such as the circuitry of the brain, the integrity of which in turn depends on an appropriate neural biochemistry. In this perspective, there is nothing wrong with the idea to attack dyslexia through an up-levelling of the brain's biochemistry that ultimately subserves reading. In this respect, the predicted effects of omega oils are of interest [43]; the same holds for medication [21]. Going the road downward one finally meets the genes. Currently, there is quite some interest in the genetic basis of reading disturbance and deviancies have been traced [44]. Thus, if gene repair comes through one might anticipate the practice of reading repair through gene repair. If so, one might be tempted to think that the genes do it all and that it doesn't much matter in which way one acquires proficiency in reading. One should realize though that the road from gene to reading is not linear. Upstream, many things may go wrong and many things may need to be corrected, using current and future treatment techniques. Even gene-driven brains are plastic and willing to change in a changing learning environment. Moreover, a gene's switching on or off is largely environmentally conditioned [45]. Thus, the important question is and remains what the best learning

environment is for a particular child hampered in learning to read.

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